THE EFFECT OF URBANIZATION ON THE DIRECT RUNOFF TO TOUBY RUN, MANSFIELD, OHIO

A SENIOR THESIS

Presented in Partial Fulfillment of the Requirements for the Bachelor of Science Degree

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INTRODUCTION

In an undisturbed drainage basin, water reaching the ground from precipitation moves to the main stream channel by any of several methods. Some water moves overland or through the upper layers of soil to be discharged into the stream relatively quickly as direct runoff. The rest infiltrates deep into the ground and reaches the stream much later. A small fraction of the water evaporates at the surface. As the basin undergoes urbanization, the amount of impervious surface and the area served by storm sewers increases, which allow less water to infiltrate and more to contribute to direct runoff. This process has the effect of increasing the amount of direct runoff to a stream as the basin becomes more urbanized.

In the area selected for study of this relationship, Touby Run drainage basin in Mansfield, Ohio, there has been urban development in the last twenty years. In this study I will try to determine whether or not there has been enough urbanization to significantly increase the amount of direct runoff entering Touby Run after periods of heavy rainfall.

Similar studies have been done on Long Island (Seaburn, 1969), in California (Crippen, 1965; Harris and Rantz, 1964), and in various places by the U.S. Geological Survey. Seaburn determined that there had been a 530 percent increase in the area served by storm sewers, with a corresponding increase in the average annual direct runoff of 270 percent. He also showed that the impervious cover had increased from 6 percent to about 27.6 percent. Crippen showed that the basin he worked in had been 45 percent urbanized, with 10 percent of the basin being under impervious cover, which produced a 40 percent increase in the peak discharge of a flood. The U.S. Geological Survey has shown that the maximum amount of the basin that can be rendered impervious, under normal urbanization, is about 32 percent.

TERMINOLOGY

RUNOFF (Adapted from Chow, 1964; p. 14-2)

Runoff, or total runoff, is the part of precipitation which appears in bodies of surface water such as streams, rivers, or lakes. When this water is collected from a drainage basin it passes through the outlet of the basin.

Runoff can be divided into several components, depending upon their mode of travel to the body of water. Surface runoff is the part of total runoff that reaches the stream or lake by travelling over the land surface, or through channels such as paved streets or storm sewers. Subsurface runoff is due to precipitation that infiltrates the upper layers of soil, then moves laterally through these layers to be discharged into the stream or lake as shallow groundwater above the main water table. This can be further divided into prompt subsurface runoff and delayed subsurface runoff. These are divided differently, depending on the particular project, but such division is not important here. Groundwater runoff, or groundwater discharge, comes from precipitation that infiltrates deep into the soil, becomes groundwater, then discharges, much later, into the stream or lake.

The above division of runoff is useful in highly complex engineering problems. However an easier and more practical division exists, and will be used here. Total runoff can be separated into direct runoff and base flow. Direct runoff is that part of the precipitation which enters a stream or lake promptly after reaching the ground. It consists of surface runoff, prompt subsurface runoff, and channel precipitation (channel precipitation is precipitation that falls directly on the body of water, and is usually considered as a part of surface runoff). Base flow is the sustained or perennial flow in a body of water, and consists of groundwater runoff and delayed subsurface runoff.

PRECIPITATION (Adapted from Chow, 1964; pp. 14-2, 14-3)

Precipitation can occur in many forms such as snow, rain, sleet, or hail, however in this study only rainfall is considered, and precipitation will be taken as being synonymous with rainfall.

Total precipitation consists of the abstractions and precipitation excess. The abstractions are that part of the precipitation which does not become part of surface runoff, and are controlled by one or more of the following; evaporation, transpiration, infiltration, interception, and depression storage. These in turn are controlled by such things as temperature, humidity, barometric preassure, amount of vegetation, rate of withdrawl of groundwater, impervious surfaces, and rate of infiltration.

Precipitation excess is precipitation left over after the abstractions are taken away, and contributes directly to surface runoff. Its volume is directly affected by the amount of abstractions.

Figure 1 illustrates the relationship between total precipitation and total runoff and the various components of each.

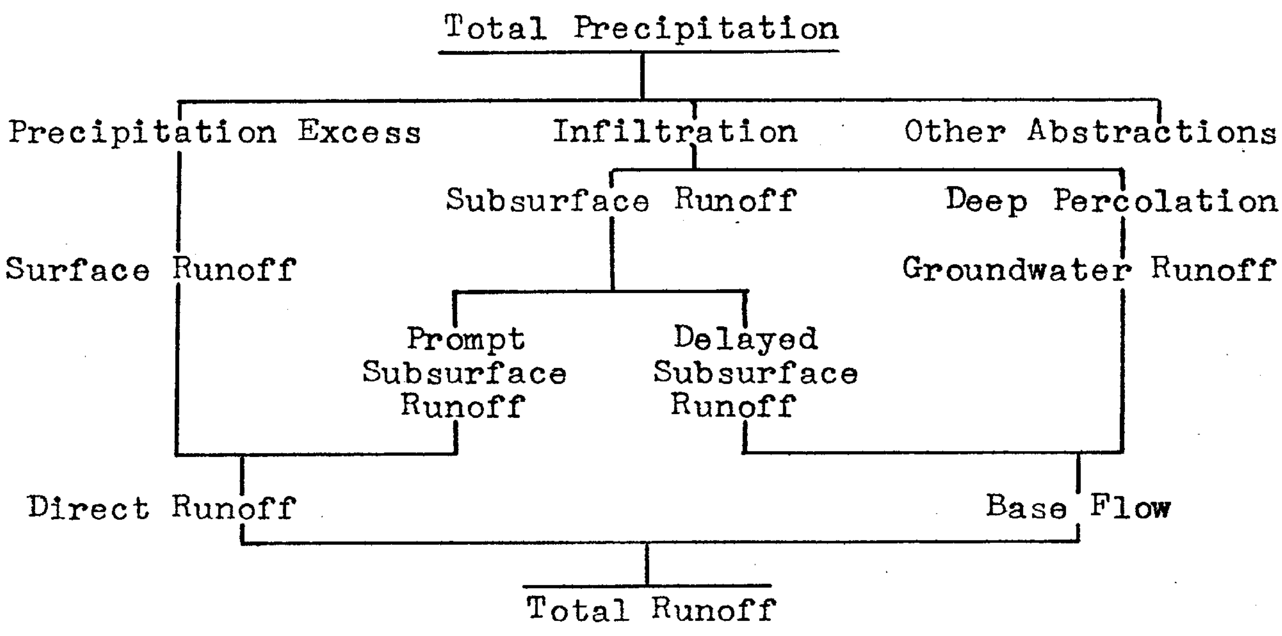


Figure 1. The relationship between total precipitation and total runoff. Modified after Chow, 1964.

URBANIZATION

Urbanization is defined as construction of residential and/or commercial establishments, roads, streets, parking lots, and other impervious surfaces, and construction of storm sewers.

SELECTION OF A STUDY AREA AND INFORMATION SOURCES

BASIC REQUIREMENTS

In a study of this type, the area under consideration must meet several requirements. The first is that there must be a continuous recording stream gage at the outlet of the basin. This gives an instantaneous hydrograph showing changes in the flow of the stream, and the time at which these changes occur. A rating table is necessary to convert this to an instantaneous discharge hydrograph.

The second qualification is that there must be a continuous recording precipitation station within or very near the basin. This allows one to have a record of the hourly rainfall, which is useful in determining rainfall intensities. The ideal situation would be to have several precipitation stations within the basin so an acurate determination of rainfall intensity and distribution over the entire basin could be attained. However this is rarely the case and usually a point source of rainfall data must be used.

The third qualification is that there must have been urban development over the period of record of the stream gage and the precipitation station.

The last qualification is that the basin should be relatively small. This makes it much easier to work with. Changes in stream flow would show more prominantly after a small storm. There would be more chance of widespread urbanization over the basin. Also there would be more chance of getting an even rainfall distribution over the entire basin for any given storm. Seaburn (1969) studied a basin of 31 square miles, and concentrated on a 10 square mile area that had been completely urbanized. Crippen (1965) considered a basin of only 245 acres.

It is hard to find an area that meets all of these requirements exactly. Usually one or more criteria are lacking. As a result, the qualifications have to be relaxed somewhat. When any of the qualifications are relaxed, sources of error are introduced that must be recognized when interpreting the data. It is possible to analyze the basin without continuous recorded data. It is also possible to use one precipitation station if several are not available. However the results will not be as accurate nor as flexible as if continuous recorded data and several stations were used.

INFORMATION SOURCES

A list of areas fulfilling the requirements for a study of this type can be compiled by matching features of areas described in several sources. A list of gaging stations in Ohio is contained in a series of circulars published by the U.S. Geological Survey called the Index of Surface Water Records. These contain the position of the stations, their period of record, the type of record kept, and the size of the drainage basin.

Precipitation stations in Ohio are given in a monthly publication called Climatological Data, published by the U.S. Environmental Data Service. It lists the positions of stations, whether it is a recording or non-recording station, and daily totals of precipitation. Also, the U.S. Geological Survey has the same information for a series of stations that they maintain throughout Ohio.

A history of the urban development in an area can be developed from records at county, city, and/or village engineering or any land use planning offices. Topographic maps can be useful in determining the amount of urbanization. Areal photos from the U.S. Geological Survey, Department of Agriculture, or private sources such as engineers, surveyors, etc. can also be useful.

The above sources were consulted for possible study areas in Ohio, however the same sources could be used to locate a study area anywhere in the United States.

DESCRIPTION OF THE STUDY AREA

The Touby Run drainage basin is located on the west side of Mansfield, Ohio. It is approximately 5.44 square miles in size. Within the basin lies a section of the city of Mansfield, a section of the village of Ontario, and the rest is under the jurisdiction of Richland County. The terrain is gently rolling, with a maximim relief of between 260 and 270 feet (Figure 2).

The U.S. Geological Survey established the Touby Run gaging station in 1946. It is a continuous water-stage recorder in a wooden reach-in shelter. Its location is 82° 32' 35'' W. Longitude, 40° 45' 55'' N. Latitude (Figure 2). The elevation of the gage is 1216.42 feet above sea level. At this gage, instantaneous hydrographs are made. Instantaneous discharge hydrographs can be made from these using a rating table for this stream. On September 12, 1970, a digital recorder was installed, which gives gage heights at predetermined times around the clock. Again, using a rating table, instantaneous discharge hydrographs can be made.

The U.S. Geological Survey also established a continuous recording precipitation station within the basin in August, 1953. It is located at 82° 34' 20'' W. Longitude, 40° 45' 25'' N. Latitude (Figure 2). A network of precipitation stations is not available so this station will serve as a point source of rainfall data for the entire basin.

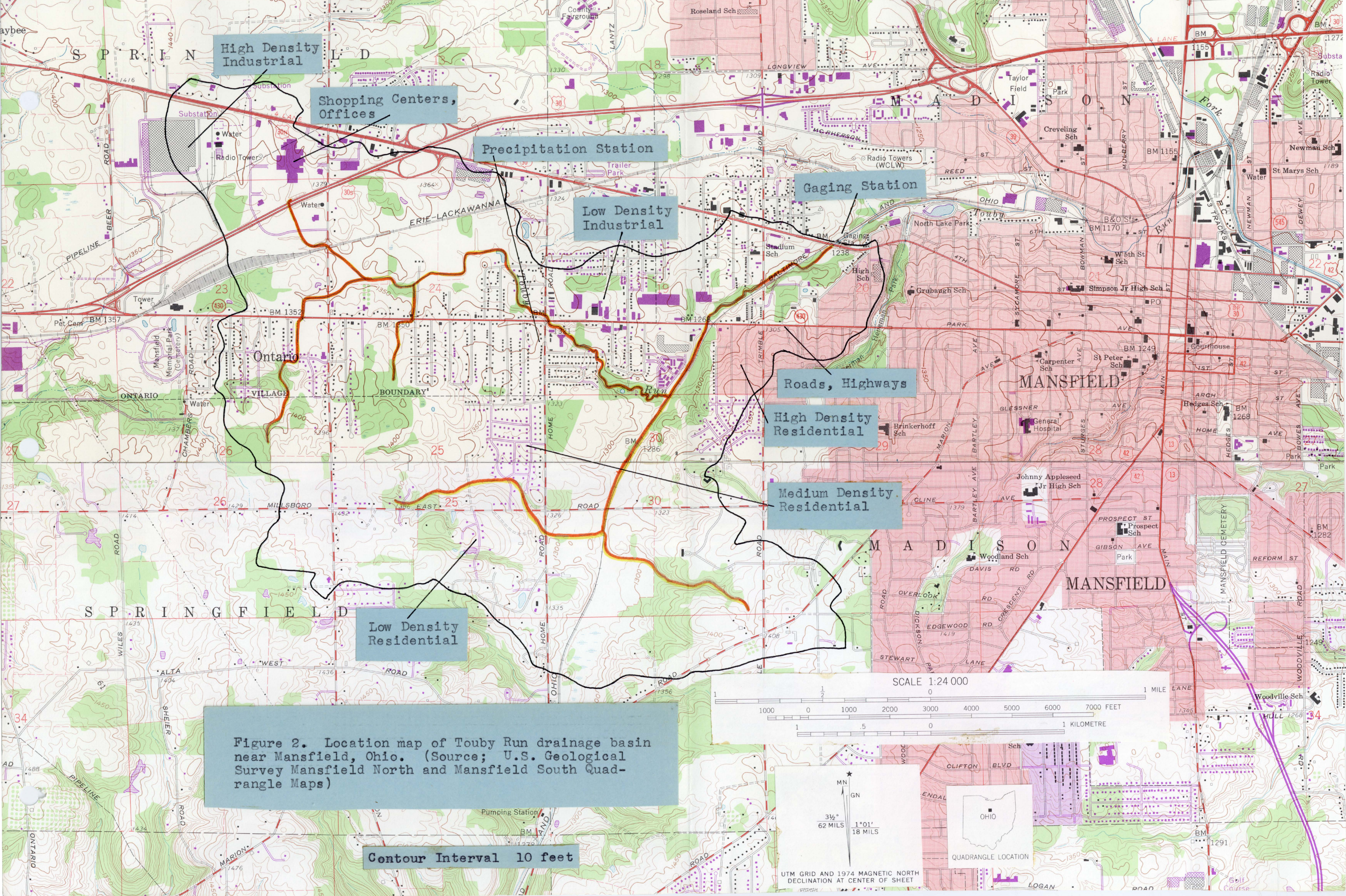


Figure 2. Location map of Touby Run drainage basin near Mansfield, Ohio. (Source; U.S. Geological Survey Mansfield North and Mansfield South Quadrangle Maps)

The Touby Run drainage basin has shown an increase in urban development since the stream gage and the precipitation station were established. Most of the area within the basin, and east of Trimble Road was already developed when the gaging station was put in, as this lies well within the limits of Mansfield. The eastern boundary of the village of Ontario lies along Home Road, at about the center of the basin. Most of the development in the village took place in the middle to late 1950's up through 1962. Since 1962 most of the development that has taken place in the village has been of the commercial type. Before the middle 1950's there was little urban development in Ontario. Urbanization within the city of Mansfield between Home and Trimble Roads, and the county land south of the Ontario boundary has all occurred in the last fifteen years.

ANALYSIS OF DATA

PROCEDURES

Urbanization Analysis

Changes in the amount of urbanization were determined by the following method. A grid was placed over a topographic map of the drainage basin. The number of nodes falling on an urbanized area was totaled for each of seven types of urbanization encountered. The number of nodes for each type of urbanization was divided by the number of nodes contained in one square mile, the quotient being the number of square miles covered by that type of urbanization. This value is multiplied by the "sampled percent impervious cover", for that particular type of urbanization, and the product is the percent of the basin under impervious cover resulting from that type of urbanization. The "sampled percent impervious cover" is a number dervied by the U.S. Geological Survey from various studies of this type (James Board, U.S.G.S., pers. comm.). It represents the percentage of an area under impervious cover, resulting from a particular type or urbanization. The number of square miles covered by each type of urbanization is coverted to the percentage of the basin covered by that type of urbanization. Examples of calculations for percent urbanization and percent impervious cover in the basin are shown in Table 1.

The above procedure was done twice, using 2 grids, one with 172.25 nodes per square mile, the other with 27.56 nodes per square mile. The values obtained for each were then averaged to get the final results.

Hydrologic Analysis

I have used two methods to compare precipitation and discharge in order to determine whether any changes have taken place within the basin. The first is the "rainfall vs. runoff graph". It is a plot of the amount of rainfall vs. the amount

Table 1. Example of Calculations Determining Area Covered by Urbanization, and Area Under Impervious Cover

Type of Urbanization	(Col. 1) Sampled Percent Impervious Cover	(Col. 2) Number of Nodes	(Col. 3) Number of Nodes/mi.^{2}	(Col. 4) Area Urbanized Col. 2/ Col. 3	Percent of Basin Under Impervious Cover Col. 4 X Col. 1	Percent of Basin Urbanized
High Density Industrial	56.5	10	100	.1 mi.^{2}	.056	3.33
Medium Density Residential	21.6	10	100	.5 mi.^{2}	.108	16.67
Totals					.164	20.00
					.005 mi.^{2}	.6 mi.^{2}

Drainage Area: 3 mi.^{2}

of direct runoff for a particular storm. It shows the relationship between the size of the storm and the amount of direct runoff, and changes that occur in this relationship as urbanization takes place within the basin (Figure 3).

The second method of analysis is a plot of the lag times for each storm. The lag time is the difference in time between the center of mass of the rainfall, and the center of mass of the direct runoff. The center of mass is the time at which one-half of either the rainfall or the direct runoff has passed (Figure 4).

The first step in analyzing the hydrologic characteristics of this basin was to establish the period of record, or the period of time over which I would look at the changes in the basin.

I decided on a period from January 1, 1954 to December 31, 1973. The former date was picked because that is when good rainfall records become available from the precipitation station. The later date was chosen because it allows the period to be broken into 4 equal groups of 5 years each. They are listed in Table 2.

From each of the four periods, five storms were chosen for analysis. Five were chosen to allow the average to be one storm per year, to get a somewhat equal distribution of events throughout the entire period of record.

Several criteria had to be fulfilled to use a particular storm for analysis. The first was that there had to be a

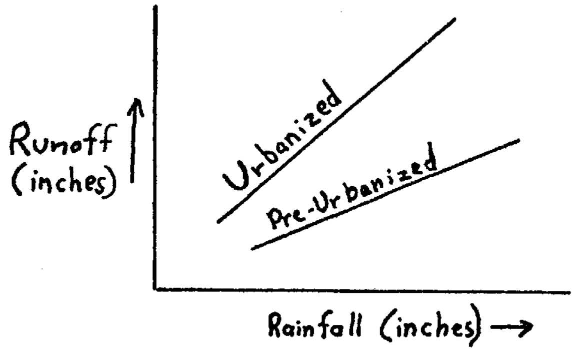


Figure 3. Example of change in rainfall vs. runoff relationship for pre-urbanized and urbanized periods.

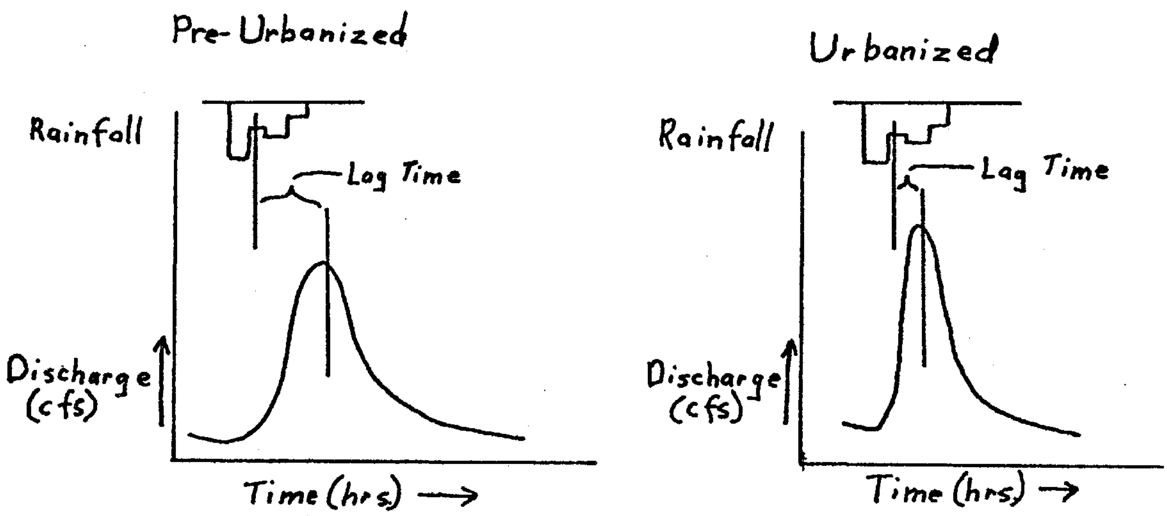


Figure 4. Example of change in lag time for pre-urbanized and urbanized periods.

Table 2. The Five Year Groups of the Period of Record

Group A:	January 1, 1954 to December 31, 1958
Group B:	January 1, 1959 to December 31, 1963
Group C:	January 1, 1964 to December 31, 1968
Group D:	January 1, 1969 to December 31, 1973

good match between the rainfall data and the stream gage data. Using the point source of rainfall data affects this because a storm may be centered in a part of the basin such that only a fraction of the total precipitation is recorded at the precipitation station, yet a very high peak will show on the stream gage data. The second qualification was that the charts from these two sources had to be of sufficient quality to permit easy retrieval of the information. Some of the charts had been damaged either by water or by mis-handling, and the information on them was unreadable. Thirdly, the rainfall should have been as evenly distributed as possible over the period of the storm. This avoids having multiple peaks on the hydrograph, which complicates the analysis. It is best if the hydrograph started and ended at the base flow level. Therefore the chosen storm should not have been preceded or suceeded too closely by any other rainfall. Lastly, I wanted to choose and analyze storms with the widest possible ranges of magnitude.

After the storms were chosen, the next step was to determine the amount of direct runoff produced by each storm. To do this instantaneous discharge hydrographs were developed, using the proper rating table, and the base flow was separated from the direct runoff by the method described in Appendix I. At each hour, beginning at the point of rise (Appendix I), the amount of base flow in cubic feet per second (cfs) was subtracted from the amount of total flow. This gives the amount of direct runoff in cfs at a particular hour. These hourly values were summed, and the total divided by the number of measurements, or values, per 24 hours, in this case 24. This gives the amount of direct runoff in second foot days (sfd). One sfd is equal to a flow of 1 cfs flowing for 1 day. This volume was then converted to inches. One sfd is equal to 1.492992×10^8 cubic inches, or the number of seconds in one day, 86,400, times the number of cubic inches in one cubic foot, 1,728. This is divided by the number of square inches within the drainage basin, 4.0144896×10^9 square inches per 1 square mile, times 5.44 square miles; or 2.1838823×10^{10} square inches. This quotient is multiplied by the number of sfd's of direct runoff to give the amount of direct runoff, in inches.[1] See Table 3 for an example. The amount of precipitation, in inches, was then plotted against the amount of direct runoff, in inches, for that storm in a log-log plot.

I next wanted to look at the lag times of the individual storms. The rainfall data were displayed on a hyetograph, plotted on the same time base as the discharge hydrograph associated with it. The duration of the storm was broken into units, in this case of two hours. The ordinates represent the amount of rainfall that occurred in a particular two hour period. To find the center of mass of the rainfall, the time must be found when one half of the rainfall has occurred.

1 This method is described in Linsley, Kohler, and Paulhus; 1958 p. 197

Table 3. Example of Calculations to Determine Amount of Direct Runoff

Date	Hour	Base Flow (cfs)	Total Flow (cfs)	Direct Runoff (cfs)
8/10/71	Noon	0.62	0.62	0.00
	1pm	0.80	8.25	7.45
	2	1.00	35.60	34.60
	3	1.25	60.00	58.75
	4	1.30	38.80	37.50
	5	1.50	29.00	27.50
	6	1.75	22.70	20.95
	7	1.90	14.50	12.60
	8	2.00	8.40	6.40
	9	2.10	5.20	3.10
	10	2.25	3.88	1.63
	11	2.40	2.80	0.40
	Mid.	2.62	2.62	0.00
			Total:	210.88

1 sfd = 1 cfs flowing 1 day

1 day = 86,400 seconds

$1 \text{ ft.}^3 = 1{,}728 \text{ in.}^3$

$1 \text{ sfd} = 1.492992\text{x}10^8 \text{ in.}^3$

$1 \text{ mi.}^2 = 4.0144896\text{x}10^9 \text{ in.}^2$

$5.44 \text{ mi.}^2 = 2.1838823\text{x}10^{10} \text{ in.}^2$

Direct Runoff (DR) =

$$\frac{\#\text{ of in.}^3 \text{ per 1 sfd}}{\#\text{ of in.}^2 \text{ per basin}} \left(\#\text{ sfd of DR}\right)$$

$$\frac{210.88}{24} = 8.79 \text{ sfd} \qquad \frac{(8.79)\ 1.492992\text{x}10^8}{2.1838823\text{x}10^{10}} = .060 \text{ in.}$$

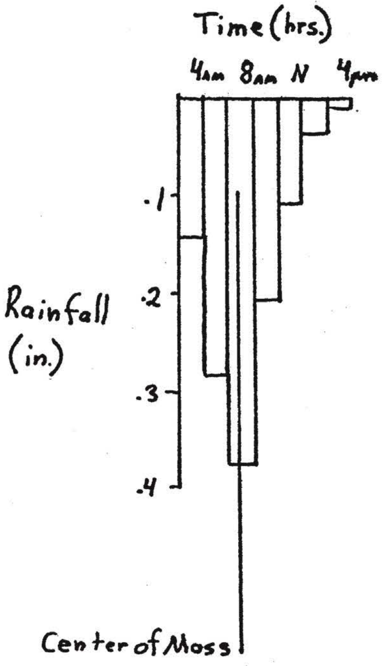
Direct Runoff = .060 in.

An example of how this is done is shown in Table 4. The center of mass of the direct runoff must also be found, and is done in a similar fashion, which is shown in Table 5.

Table 4. Example of Calculation of Center of Mass of Rainfall, and an Example of a Hyetograph

Unit	Amt. of Rainfall (in.)	Cumulative Total (in.)
1	.140	.140
2	.285	.425
		← .600
3	.375	.800
4	.230	1.030
5	.120	1.150
6	.040	1.190
7	.010	1.200

Total: 1.200



$$\frac{1.200}{2} = .600$$

$$\left.\begin{array}{l} .425 \\ .600 \end{array}\right\} \text{difference} = .175$$

$$\left.\begin{array}{l} .600 \\ .800 \end{array}\right\} \text{difference} = .375$$

$$\frac{.175}{.375} = \frac{X}{100} \qquad X = 46.67\%$$

$$\frac{46.67}{100} = \frac{X}{120} \qquad X = 56 \text{ min.}$$

Time of Center of Mass = 6:56 A.M.

Table 5. Example of Calculation of Center of Mass of Direct Runoff

Date	Hour	Direct Runoff (cfs)	Cumulative Total (cfs)	
8/10/71	Noon	0.00	0.00	
	1pm	7.45	7.45	
	2	34.60	42.05	
	3	58.75	100.80	← 105.44
	4	37.50	138.30	
	5	27.50	165.80	
	6	20.95	186.75	
	7	12.60	199.35	
	8	6.40	205.75	
	9	3.10	208.85	
	10	1.63	210.48	
	11	0.40	210.88	
	Mid.	0.00	210.88	
	Total:	210.88		

$$\frac{210.88}{2} = 105.44$$

100.80 } difference = 4.64
105.44
138.30 } difference = 37.50

$$\frac{4.64}{37.50} = \frac{X}{100} \qquad X = 12.4\%$$

$$\frac{12.40}{100.00} = \frac{X}{60} \qquad X = 7 \text{ min.}$$

Time of Center of Mass = 3:07 pm

RESULTS

Urbanization

Application of the procedure described earlier indicates that the portion of the basin urbanized has risen from 6.5 percent, or 0.35 square miles, in 1954, to 24.4 percent, or 1.3 square miles in 1973. The percentage of the basin that is under impervious cover has risen from 0.16 percent in 1954 to 0.5 percent in 1973. These totals are the result of urbanization of several types, which are listed, along with their values, in Table 6.

Table 6. Changes in Urbanization and Impervious Cover

Type of Urbanization	Percent of Basin Urbanized 1954	Percent of Basin Urbanized 1973	Percent of Basin Impervious 1954	Percent of Basin Impervious 1973
Roads and Highways	2.800	6.250	0.100	0.225
Shopping Centers, Offices	0.000	2.150	0.000	0.060
High Density Industrial	0.000	2.150	0.000	0.035
Low Density Industrial	0.000	0.650	0.000	0.008
High Density Residential	3.000	3.000	0.050	0.050
Medium Density Residential	0.700	9.500	0.010	0.120
Low Density Residential	0.000	0.675	0.000	0.005
Totals:	6.500	24.400	0.160	0.500
	0.35 mi^2	1.3 mi^2		

Hydrologic Characteristics

Figure 5 is a log-log plot of the amount of direct runoff vs. the amount of rainfall, for each storm. The slope of the plotted points reflects the relationship between the two. The greater the slope, the more direct runoff is produced for a given amount of precipitation. A change in the slope indicates a change in this relationship. As a basin becomes urbanized a greater percentage of precipitaion will contribute to direct runoff. Therefore in the later 5-year groups, the slope of the line through the points should be greater than that for the earlier groups, if there has been an increase in the amount of direct runoff.

In Figure 5 the points all lie within a fairly well-defined group, and all lie along the same general trend. There is no significant change in the trend of the plotted points from group to group. As is expected, the graph shows that a greater amount of rainfall produces a greater amount of direct runoff. This increase is greater than a 1:1 ratio. Since the soil can hold only a given amount of moisture, any excess will contribute to direct runoff. When a greater amount of rainfall occurs, more of the water will be forced to run off.

Figure 6 is a plot of the lag times for each storm. As the basin becomes more urbanized the lag times should decrease. Less water will be able to infiltrate, and a greater amount of direct runoff will reach the stream in the same amount of

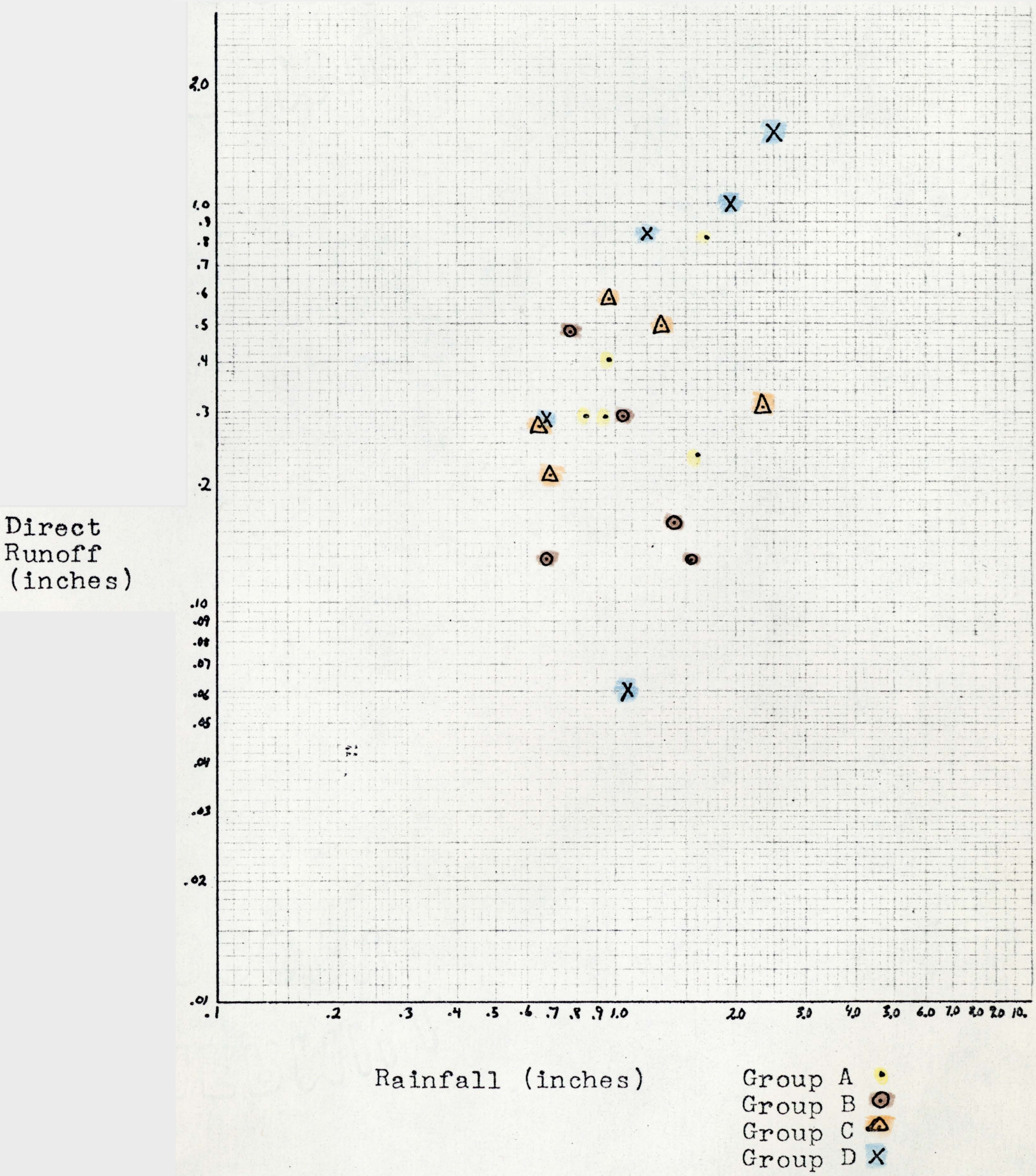


Figure 5. Log-Log plot of rainfall vs. direct runoff.

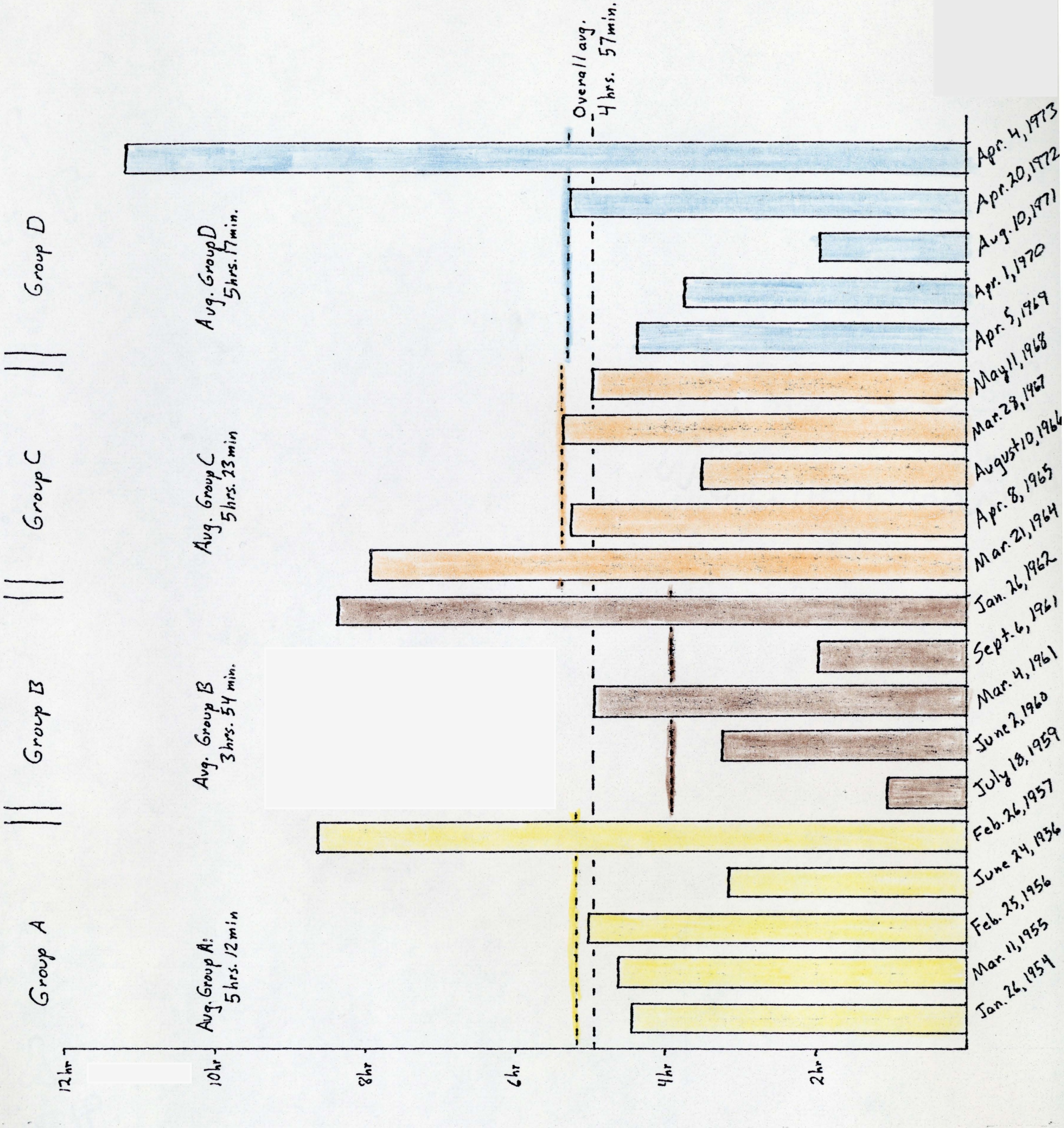


Figure 6. Lag times for each storm.

time as a lesser amount of runoff for a storm in a pre-urbanized period. Since the center of mass of the runoff is the time when one half of the runoff has passed the gaging station, the lag time should decrease.

In Figure 6 the lag times fluctuate randomly throughout the period of record. They also fluctuate randomly within each 5-year group. The average for each group is also plotted. There is a decrease in the average lag time from Group A to Group B, however the average jumps up again in Group C to a value greater than Group A. There is no significant trend in the lag times through the period of record.

There are several sources of error in the procedure I used, which should be considered, and may have affected the results somewhat. Only a point source of rainfall data was available instead of the desired network of recording stations. The point source gives the amount and time distribution of precipitation at that point, not the overall distribution for the basin. If the storm was centered in a part of the basin away from the recording station, the amount of rainfall recorded would be different than the actual amount of rainfall over the entire basin. This could have two effects. The actual rainfall runoff relationship would be different than the one determined, because the amount of rainfall would be different. Several wrong values could change the slope of the line representing the relationship, either increasing or decreasing the slope. The lag time would also be affected. The center of mass of the rainfall depends upon the amount and time distribution. Therefore the actual center of mass could be quite different than the one determined, and would cause the actual lag time to be either shorter or longer than the value used in analysis.

To counteract this problem a network of continuous recording precipitaion stations could be established. There are reliable methods of determining an overall value of precipitation for a basin from several recording stations (Chow, 1964; Linsley, Kohler, and Paulhus, 1958).

A second source of error comes from the condition of the soil. Antecedent soil moisture, or the moisture already in the soil before the time in question, and whether the ground is frozen or not, would affect the amount of direct runoff from a storm. The greater the antecedent soil moisture, the greater the amount of direct runoff produced from any given amount of precipitation. Also the greater the degree to which the soil is frozen, the greater will be the amount of direct runoff. These two factors could affect the rainfall runoff relationship. For a particular amount of rainfall, different amounts of runoff would be produced under different soil conditions.

To correct for these factors, a network of monitoring stations could be established to keep track of the soil conditions. These results would then be accounted for in the values for the direct runoff. In this particular study, the time and resources were not available to do this.

CONCLUSIONS

The information in Figures 5 and 6 show that there has been no significant change in the direct runoff, over the period of record. The amount of urbanization that I have estimated to have taken place is evidently too small to alter the regime of the precipitation and runoff. I have estimated that approximately 1.3 square miles of the basin have been developed. This development has been spread throughout the basin, rather than concentrated in one particular area. If it had been concentrated, perhaps a change would have occurred. However, there is only approximately 0.5 percent of the basin under impervious cover, and this may not be enough to effect a change in the runoff, even if it were highly concentrated.

In the future, as more urbanization takes place, a change could occur. This area will have the available recorde to do a study of this type to see if further development will result in increased direct runoff. If this indeed does occur, there will be several effects. First of all, the lag time for a storm should decrease. Also, flood peaks will be higher due to the increased runoff. Less water would be able to infiltrate to become groundwater, so the water table could fall. If groundwater is used as a source of public water, it would become harder to get, and undoubtedly more expensive to use.

FURTHER WORK

A study of this type can be done in any area that meets the aforementioned requirements. Using different techniques and procedures, different types of changes can be looked at than those in this study, but with the overall purpose of determining how changes within the basin have affected streamflow.

In Akron, Ohio there are two gaging stations at the outlet of basins, which could be utilized for a similar study. They are the Springfield Lake Outlet, and the station on the Little Cuyahoga River at Massillon Road. Both are listed in the aforementioned Index of Surface Water Records. They were established in 1946, so some change in the urban pattern must have occurred since then.

Near New Philadelphia, Ohio lies the Home Creek drainage basin, with a gaging station which was established in 1936. There has been some strip mining within this basin, and the techniques used in this study could be modified to determine the effect of the strip mining.

One of the big problems in doing a study such as this is finding a relatively small basin, with the necessary stream gage records. It seems in the past that the main concern has been to obtain information from large streams occupying large basins. However the trend seems to be changing now. As people are becoming more concerned with their nearby surroundings, the emphasis seems to be shifting toward studying smaller streams. Perhaps the shift will allow for more gaging stations being placed on small streams, then more work of this and similar type can be done.

APPENDIX I

SEPARATION OF DIRECT RUNOFF FROM BASE FLOW ON A DISCHARGE HYDROGRAPH

After a period of precipitation, two components are represented in the flow of a stream, the direct runoff and the base flow. When the stream flow is plotted as a discharge hydrograph these two components can be separated, and the volume of each determined. There are several common methods for doing this and they range in complexity. First, we should define the parts of a hydrograph. They are shown in Figure A.

AB approach segment

BC rising segment

CD recession segment

B point of rise

C peak

B and D represent the same discharge

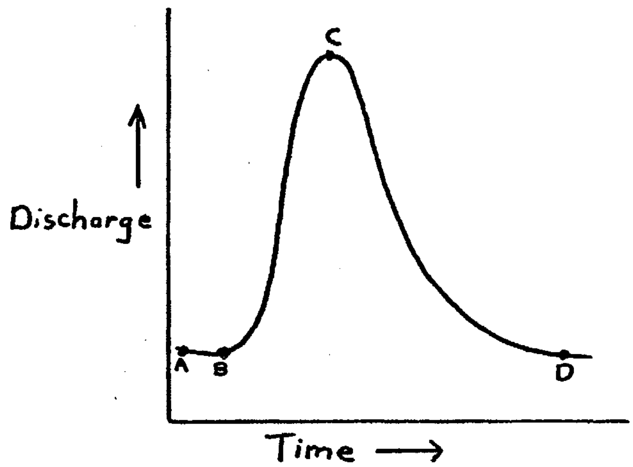


Figure A. The parts of a hydrograph (Adapted from Chow, 1964; p. 14-9).

Linsley, Kohler, and Paulhus (1958), and Chow (1964), report that there is no way to distinguish the direct runoff from the base flow in a stream at any particular time, and also that the definitions of these two compontnts are somewhat arbitrary. Therefore, the method of separating the components on the hydrograph is also arbitrary, and the differences in volume of the components from one method to another are minimal.

The easiest and simplest method of separating base flow from direct runoff is to draw a straight line from the point of rise, to a point on the recession segment with the same discharge as the point of rise, a line BD on Figure A. Everything above the line is direct runoff, everything below is base flow.

Another method involves the formula $N = A^{.2}$, where $N =$ time in days, and $A =$ the area of the drainage basin is square miles. A verticle line is drawn from the peak, line CE in Figure B. A horizontal line is drawn to the right from the point of rise, line BE in Figure B. Next, a line N days long is drawn horizontally from line CE, such that it intersects the recession segment, line FG in Figure B. A line is then drawn from E to G. Line BEG represents the line separating base flow and direct runoff.

A third method also involves the value N. The approach segment is extended to a point under the peak of the hydrograph, line BE in Figure C. Then a straight line is drawn to the recession segment, intersecting N days after the peak, line EF of Figure C. Line BEF represents the separation of direct runoff and base flow. This is done because as the flow of the stream increases, some water flows into the banks, therefore the amount of base flow should decrease (Linsley, Kohler, and Paulhus, 1958).

Many times, on the charts I used, the discharge did not reutrn completely to the discharge at the point of rise before another storm occurred and the stream rose again. Therefore, I have chosen my own arbitrary method of separating direct runoff and base flow. I have drawn a straight line from the point of rise, to a point on the recession segment that represents 2 cubic feet of discharge greater than that at the point of rise. I have used this method consistently with all the hydrographs and feel that it will work satisfactorily.

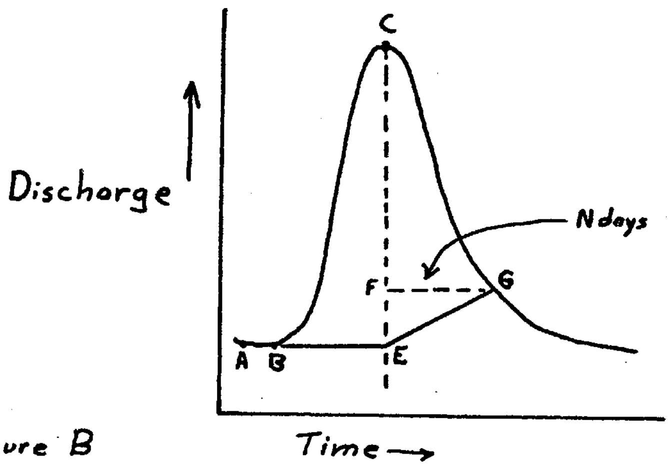


Figure B

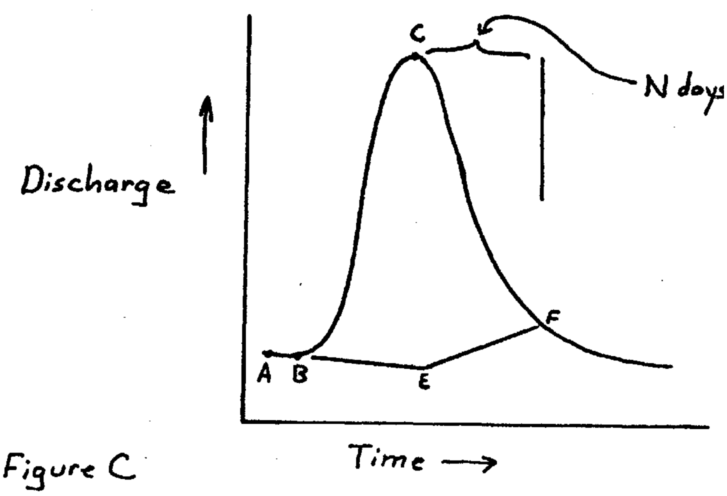


Figure C

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